providing a larger share of transponder power to disadvantaged mobile terminals and a smaller share to normally advantaged terminals, without significantly degrading overall signal quality.

Additional tests were completed in 1988 and 1991, directed toward testing CDMA as a cellular transmission modulation technique. The 1991 tests demonstrated a complete cellular system, including connection to the Public Switched Telephone Network, complete handoff facility between cells, call set up and tear down. Additional tests of microcell operation and wireless local loop applications are now in progress. This thorough testing program has established that CDMA provides for greater spectrum efficiency than other modulation access schemes such as TDMA. The testing also proves that high capacity and quality transmissions can be achieved without a complex satellite system such as Motorola's.

Thus, LQSS has, through its separate supplemental material filed today, as well as its original pioneer's preference request and other filings, provided a basis for a grant of a preference for the Globalstar™ system.

VII. Conclusion

Based on the foregoing, LQSS urges the Commission not to grant a pioneer's preference to Motorola Satellite Communications, Inc., for the Iridium™ system, but rather, grant a pioneer's preference to LQSS for the demonstrated technological innovations embodied in the Globalstar system which will fulfill the purposes of the Pioneer Preference rules as well as serve the public interest.

Respectfully submitted,

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APPENDIX A
CHART 1
Qualcomm Patents to be Utilized in the Globalstar™ System

PATENT NO.	DATE ISSUED	INVENTION
U.S. Patent No. 4,901,307	Feb. 13, 1990	Spread Spectrum Multiple Access Communication System Using Satellite or Terrestrial Repeaters
U.S. Patent No. 5,056,109	Oct. 8, 1991	Method and Apparatus for Controlling Transmission Power in a CDMA Cellular Telephone System (System)
U.S. Patent No. 5,099,204	March 24, 1992	Linear Gain Control Amplifier
U.S. Patent No. 5,101,501	March 31, 1992	Method and System for Providing a Soft Handoff in Communications in a CDMA Cellular Telephone System
U.S. Patent No. 5,103,459	April 7, 1992	System and Method for Generating Signal Waveforms in a CDMA Cellular Telephone System (Forward Link Modulation)
U.S. Patent No. 5,107,225	April 21, 1992	High Dynamic Range Closed Loop AGC Circuit
U.S. Patent No. 5,109,390	April 28, 1992	Diversity Receiver in a CDMA Cellular Telephone System

CHART 2
Patent Pending -- Globalstar™ System

1. Space Systems/Loral U.S. Patent Application 14586-24/91-8, Wireless Telephone Satellite Roaming System, including schematics. Filed March 29, 1991. Patent is pending.

2. European patent pending in France, Great Britain, Italy and Germany, for Wireless Telephone/Satellite Roaming System. Filed November 3, 1991.

COPIES OF QUALCOMM PATENTS
TO BE
UTILIZED IN THE
GLOBALSTAR™ SYSTEM

United States Patent [19]
Gilhousen et al.
[11] Patent Number: 4,901,307
[45] Date of Patent: Feb. 13, 1990

[54] SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS

[75] Inventors: Klein S. Gilhousen, San Diego; Irwin M. Jacobs, La Jolla; Lindsay A. Weaver, Jr., San Diego, all of Calif.

[73] Assignee: Qualcomm, Inc., San Diego, Calif.

[21] Appl. No.: 921,261

[22] Filed: Oct. 17, 1986

[51] Int. Cl.[4] H04J 13/00
[52] U.S. Cl. 370/18; 375/1
[58] Field of Search 370/18, 19, 95; 375/1

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IEEE Transactions on Aerospace and Electronic Systems, vol. AES-4, No. 5, Sep. 1968, Air-Ground, Ground-Air Communications Using Pseudo-Noise Through a Satellite, Blasbalg, Najjar, D'Antonio, Haddad, IBM Center for Exploratory Studies, IBM Space Systems Center.

IEEE Transactions on Vehicular Technology, vol. VT-27, No. 4, Nov. 1978, A Spread-Spectrum Technique for High-Capacity Mobile Communications, George R. Cooper, Raymond W. Nettleton.

Article from Telecommunication Journal, vol. 45, Jan. 1978 titled Spread-Spectrum Principles and Possible Application To Spectrum Utilization and Allocation by W. F. Utlaut.

Article from IEEE Communications Magazine, Mar. 1978 titled Cellular Land-Mobile Radio: Why Spread

(List continued on next page.)

Primary Examiner—Douglas W. Olms
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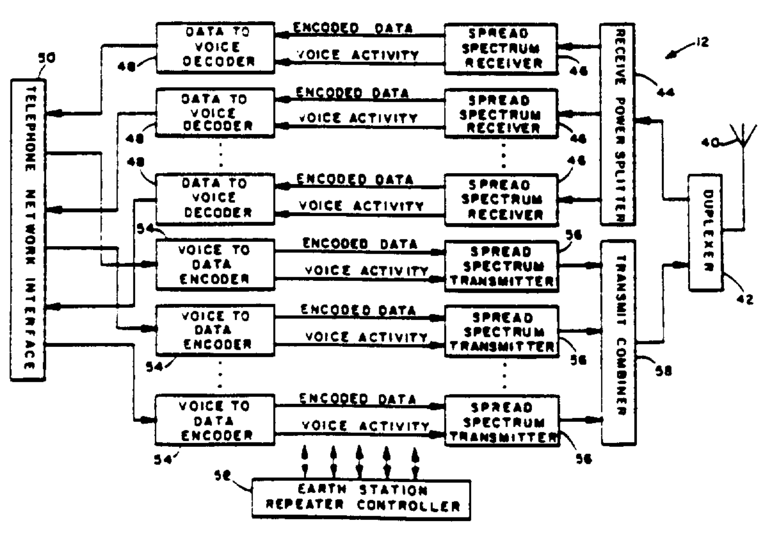
[57] ABSTRACT

A multiple access, spread spectrum communication system and method for providing high capacity communications to, from, or between a plurality of system users, using code-division-spread-spectrum communication signals. The communication system uses means for providing marginal isolation between user communication signals. The marginal isolation is provided by generating simultaneous multiple steerable beams; using an omni-directional antenna with polarization enhancement; using power control devices to adjust the output power for user generated communication signals either in response to their input activity level, or in accordance with a minimum allowable power for maintaining a communication link. The communication system can also employ a means for transmitting a predetermined pilot chip sequence contiguous with the code-division-spread-spectrum communication signals.

In further embodiments the communication system employs a plurality of user terminals linked to each other or to other services through one or more terrestrial or satellite repeaters. Multiple satellite repeaters are operable in a new communication mode to obtain further gains in signal isolation.

46 Claims, 11 Drawing Sheets



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Ad by Equatorial Communications Co. entitled Satellite Network For Point-To-Multipoint Data Distribution.
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Paper titled Subjective Evaluation of Dedicated Multiple-Hop Satellite Communications for Government and Military Users by S. Campanella, H. Suyderhoud and M. Onufry.

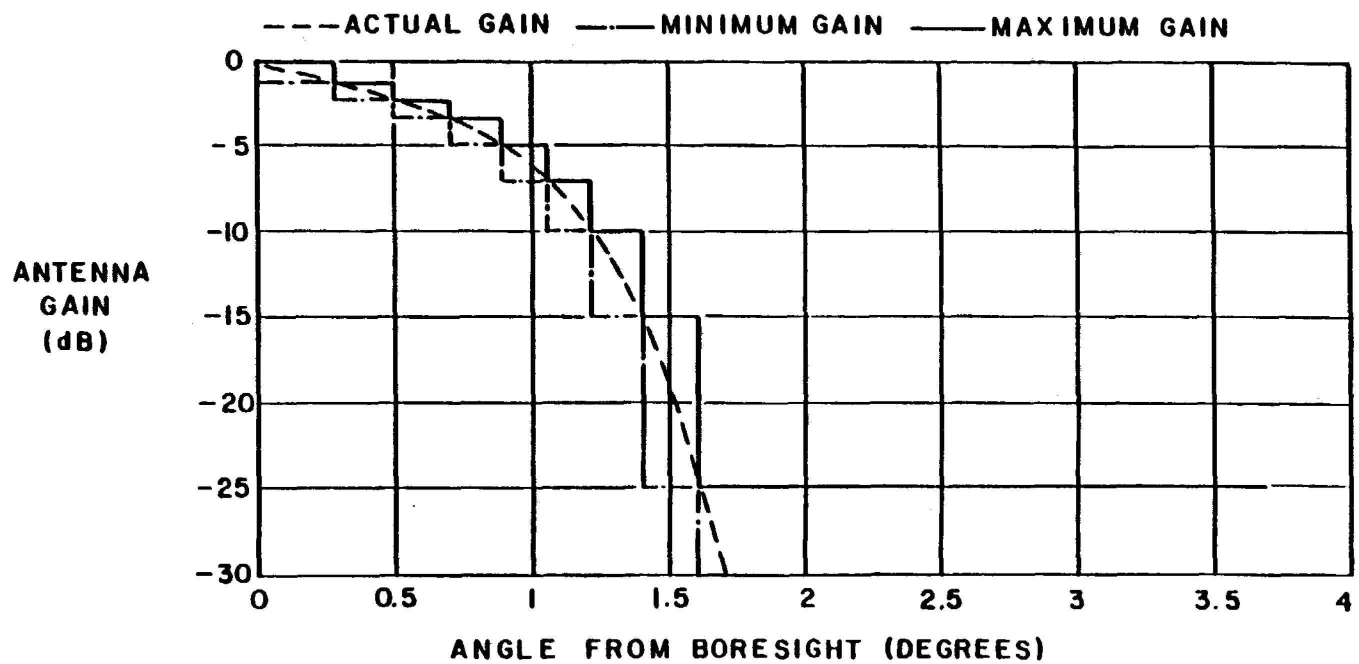
---ACTUAL GAIN
—·—MINIMUM GAIN
——MAXIMUM GAIN
ANTENNA GAIN (dB)
0
-5
-10
-15
-20
-25
-30
0
0.5
1
1.5
2
2.5
3
3.5
4
ANGLE FROM BORESIGHT (DEGREES)

FIG. 1a

ANTENNA MARGINAL GAIN

ATTN. RANGE (dB)		CUM. ANGLE (°)	Δ ANGLE (°)	# USERS (USERS)	WTD # USERS (USERS)
0	1	0.6	0.6	189	188.59
1	2	1.0	0.4	126	99.87
2	3	1.4	0.4	126	79.33
3	5	1.8	0.4	126	63.01
5	7	2.1	0.3	94	29.82
7	10	2.4	0.3	94	18.81
10	15	2.8	0.4	126	12.57
15	25	3.2	0.4	126	3.98
25	∞	7.4	4.2	1320	4.17
TOTALS			7.4	2326	500.17

FDMA REUSE FACTOR 2.64

CDMA REUSE FACTOR 4.65

FIG. 1b

RELATIVE CAPACITY INCREASE AND POLARIZATION ISOLATION vs. ELLIPTICITY

ELLIPTICITY (dB)	AXIAL RATIO	CAPACITY INCREASE	POLARIZATION ISOLATION (dB)
0.00	1.00	100%	−∞
2.00	0.63	79%	−18.81
4.00	0.40	63%	−12.91
6.00	0.25	50%	−9.57
8.00	0.16	40%	−7.32
10.00	0.10	32%	−5.69
12.00	0.06	25%	−4.46
14.00	0.04	20%	−3.51
16.00	0.03	16%	−2.78
18.00	0.02	13%	−2.20
20.00	0.01	10%	−1.74

FIG. 14

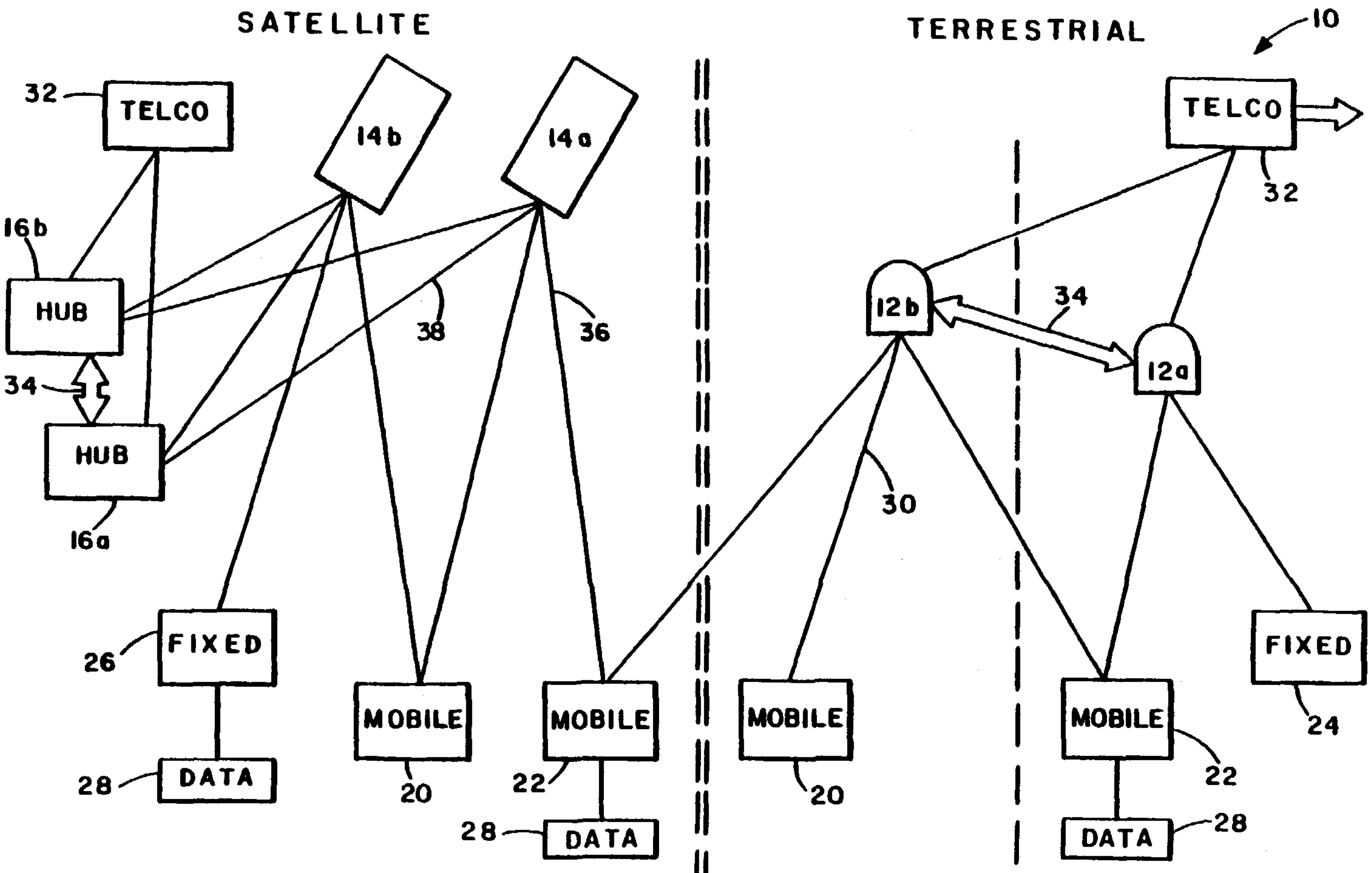
SATELLITE
TERRESTRIAL
10
32
TELCO
14b
14a
TELCO
32
16b
HUB
38
36
12b
34
12a
34
HUB
16a
30
FIXED
26
MOBILE
MOBILE
MOBILE
MOBILE
FIXED
24
28
DATA
20
22
20
22
28
DATA
DATA
28
RURAL
SUBURBAN
URBAN

FIG. 2

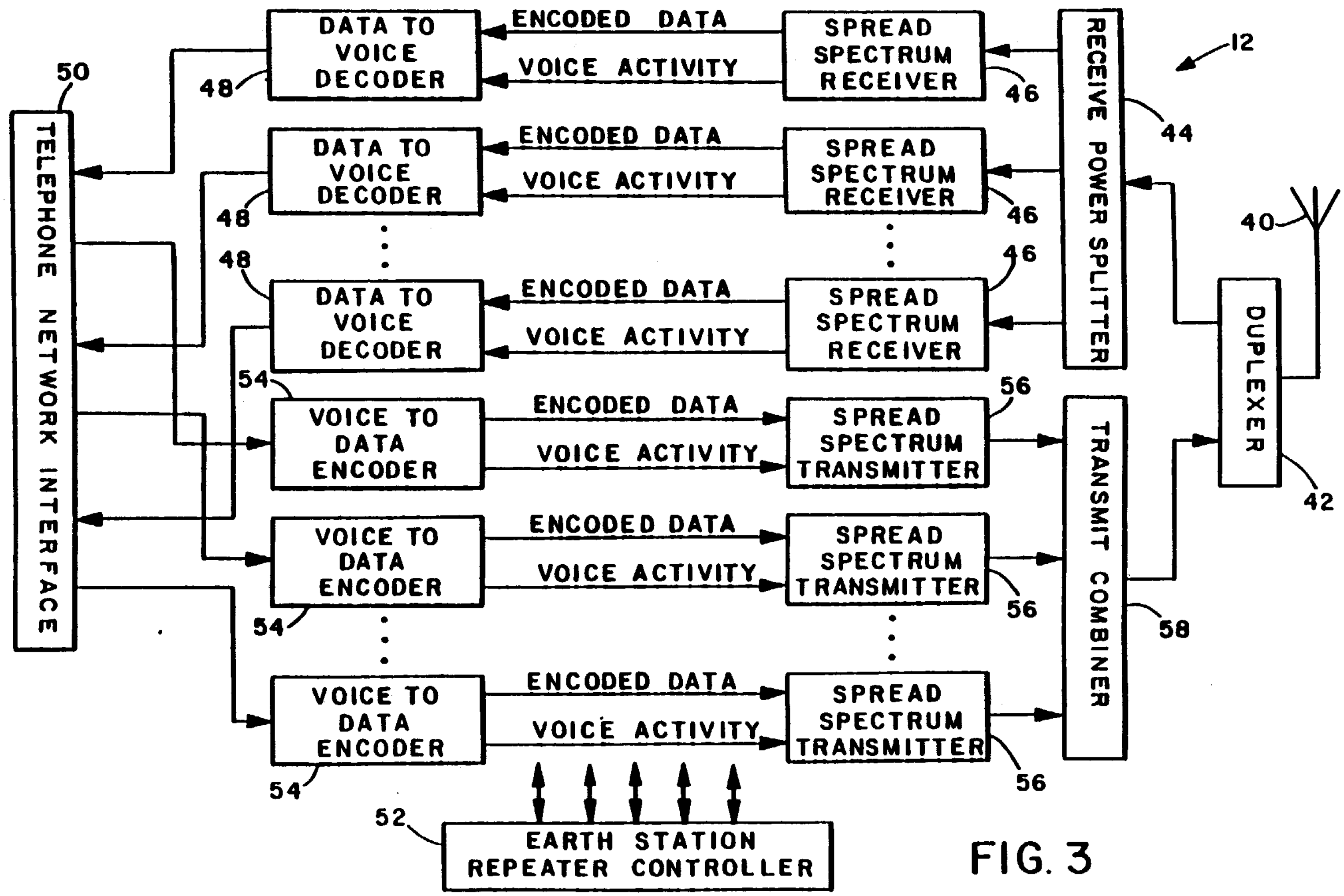
12
DATA TO VOICE DECODER
ENCODED DATA
VOICE ACTIVITY
SPREAD SPECTRUM RECEIVER
RECEIVE POWER SPLITTER
TELEPHONE NETWORK INTERFACE
VOICE TO DATA ENCODER
SPREAD SPECTRUM TRANSMITTER
TRANSMIT COMBINER
DUPLEXER
EARTH STATION REPEATER CONTROLLER
40
42
44
46
48
50
52
54
56
58

FIG. 3

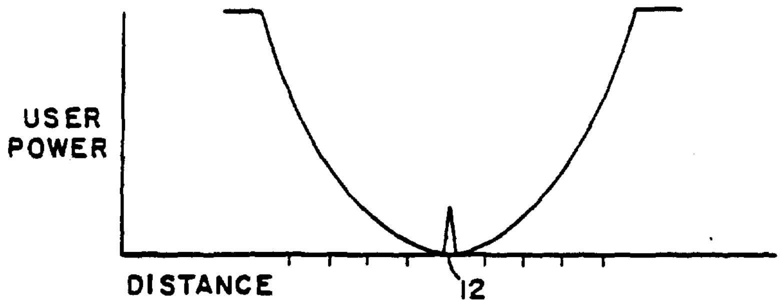

FIG. 4

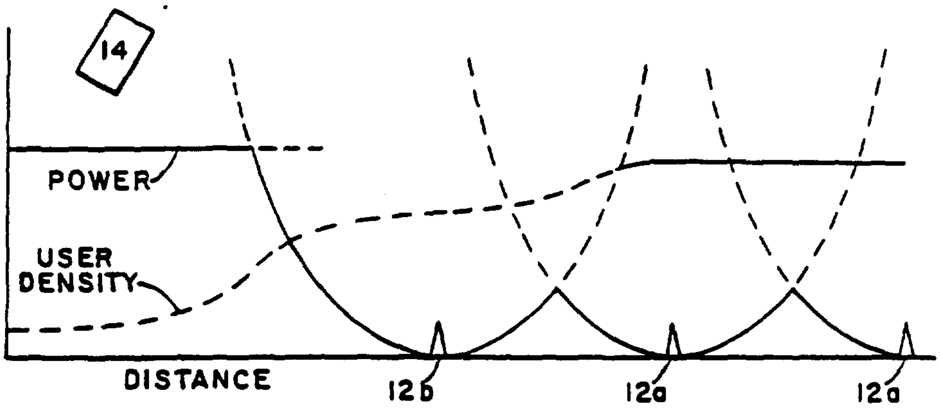

FIG. 6

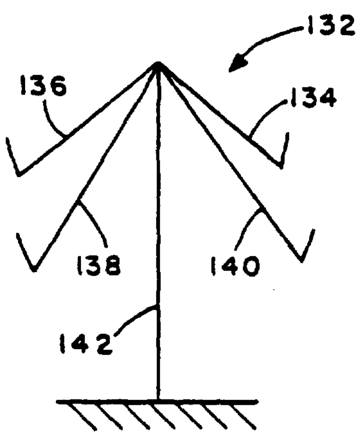

FIG. 11

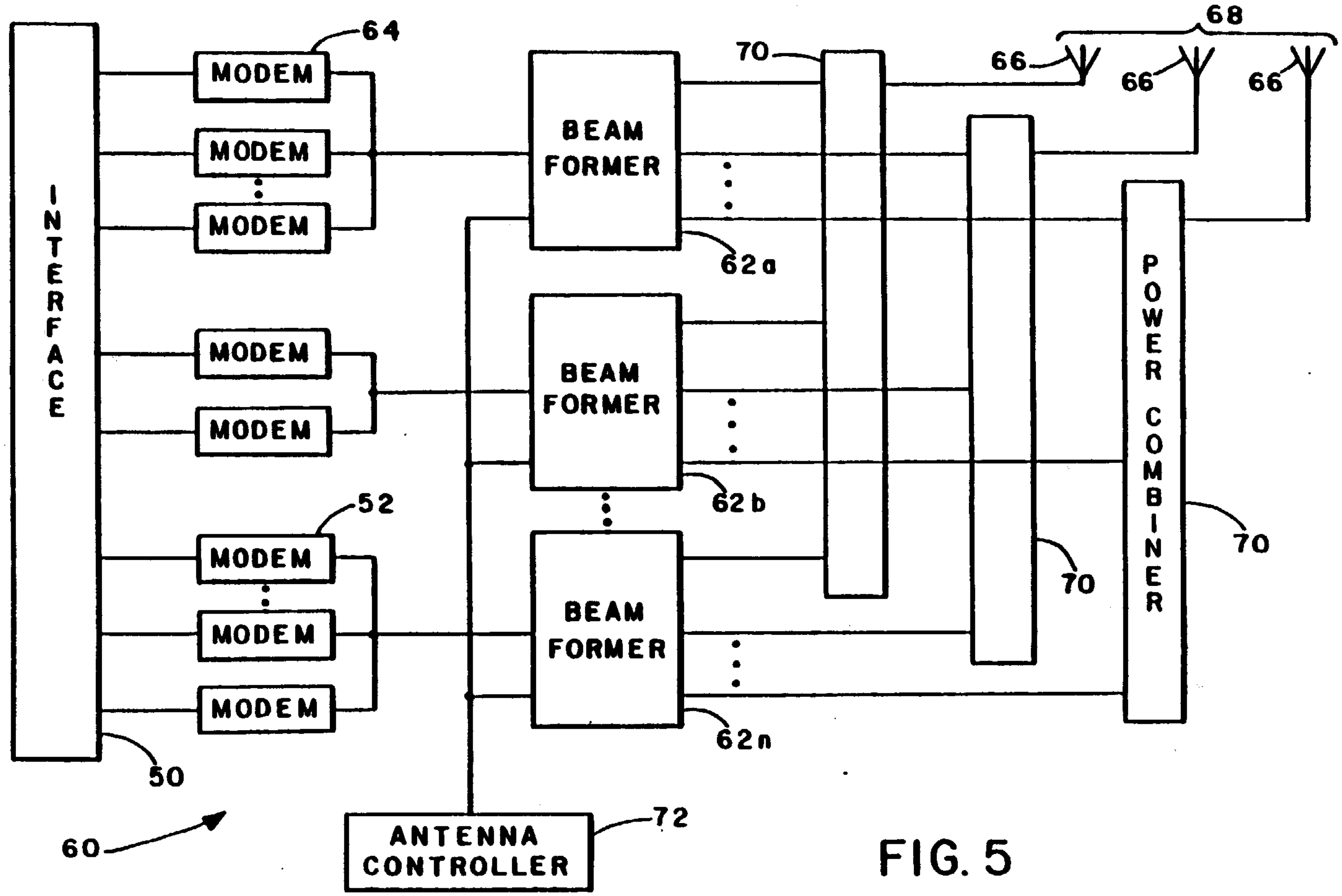
INTERFACE
MODEM
MODEM
MODEM
MODEM
MODEM
MODEM
MODEM
MODEM
BEAM FORMER
BEAM FORMER
BEAM FORMER
POWER COMBINER
ANTENNA CONTROLLER
64
52
50
60
70
70
70
70
62a
62b
62n
66
66
66
68
72

FIG. 5

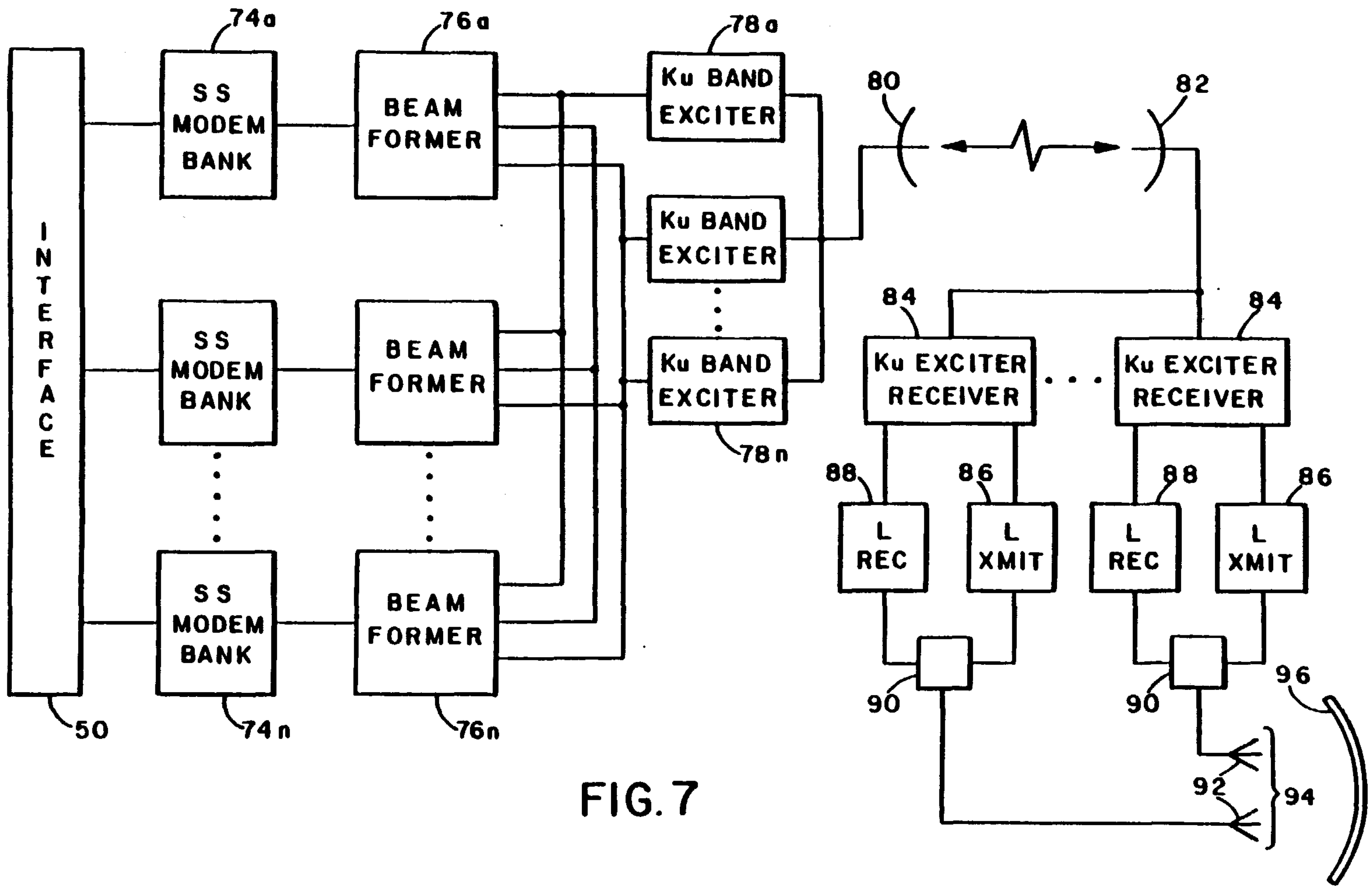
INTERFACE
50
SS MODEM BANK
74a
74n
BEAM FORMER
76a
76n
Ku BAND EXCITER
78a
78n
80
82
84
Ku EXCITER RECEIVER
88
86
L REC
L XMIT
90
92
94
96

FIG. 7

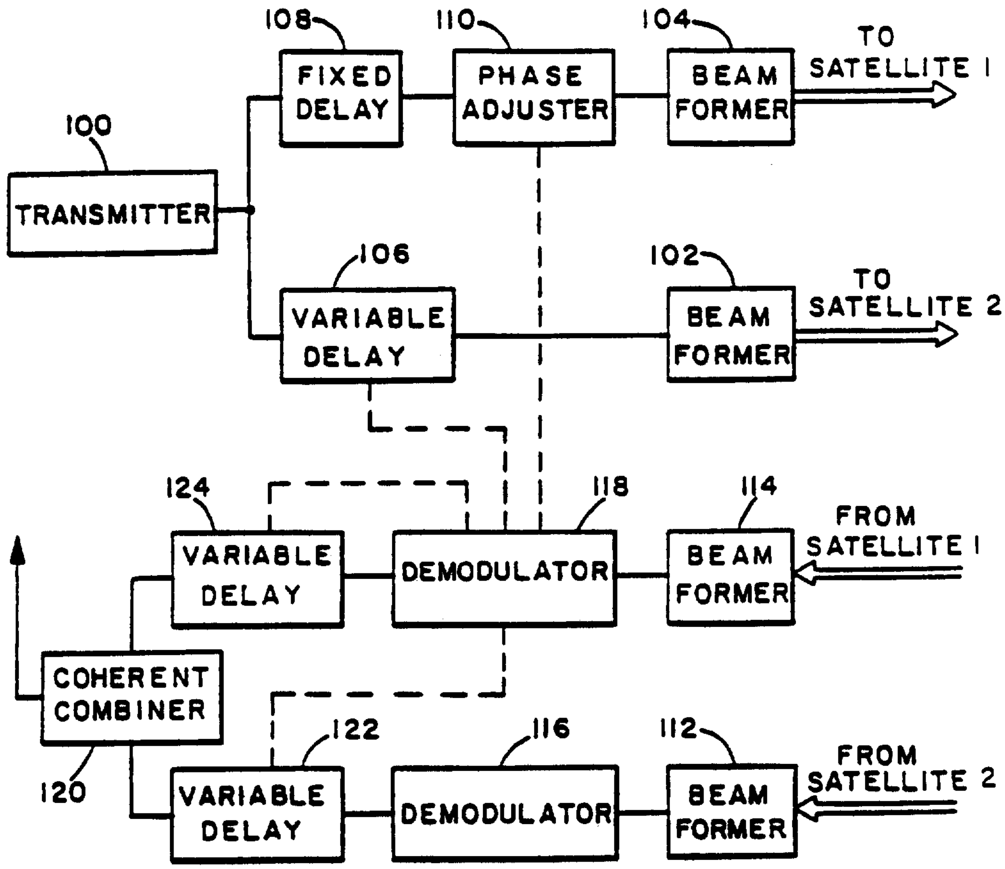
108
FIXED DELAY
110
PHASE ADJUSTER
104
BEAM FORMER
TO SATELLITE 1
100
TRANSMITTER
106
VARIABLE DELAY
102
BEAM FORMER
TO SATELLITE 2
124
VARIABLE DELAY
118
DEMODULATOR
114
BEAM FORMER
FROM SATELLITE 1
COHERENT COMBINER
120
122
VARIABLE DELAY
116
DEMODULATOR
112
BEAM FORMER
FROM SATELLITE 2

FIG. 9

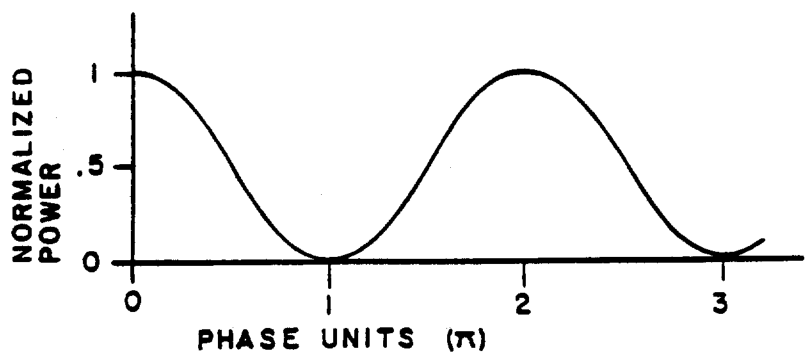
NORMALIZED POWER
1
.5
0
0
1
2
3
PHASE UNITS (π)

FIG. 8

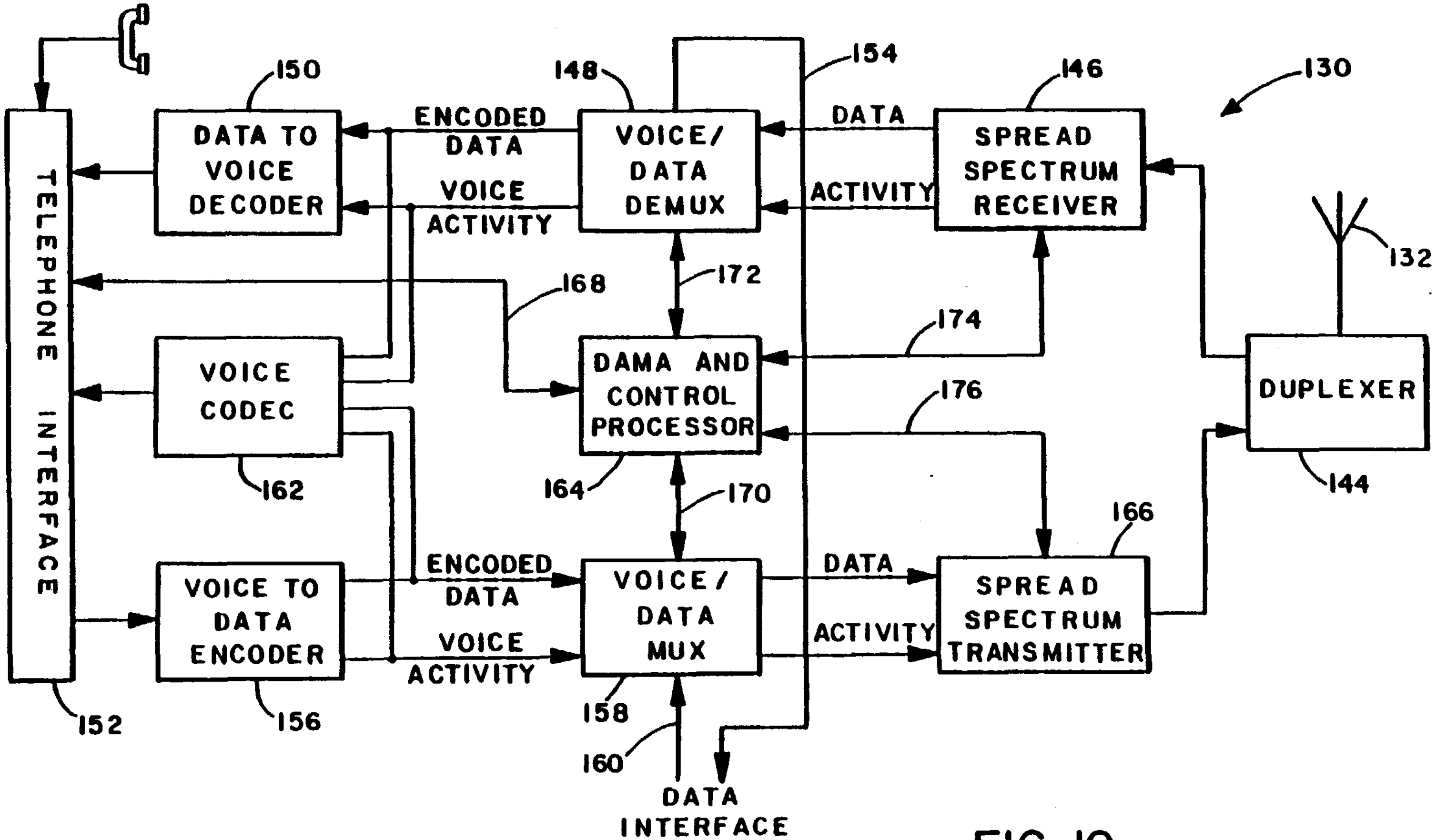
130
132
DUPLEXER
144
SPREAD SPECTRUM RECEIVER
146
SPREAD SPECTRUM TRANSMITTER
166
DATA
ACTIVITY
DATA
ACTIVITY
154
VOICE/ DATA DEMUX
148
DAMA AND CONTROL PROCESSOR
164
VOICE/ DATA MUX
158
172
174
176
170
168
160
DATA INTERFACE
ENCODED DATA
VOICE ACTIVITY
ENCODED DATA
VOICE ACTIVITY
DATA TO VOICE DECODER
150
VOICE CODEC
162
VOICE TO DATA ENCODER
156
TELEPHONE INTERFACE
152

FIG. 10

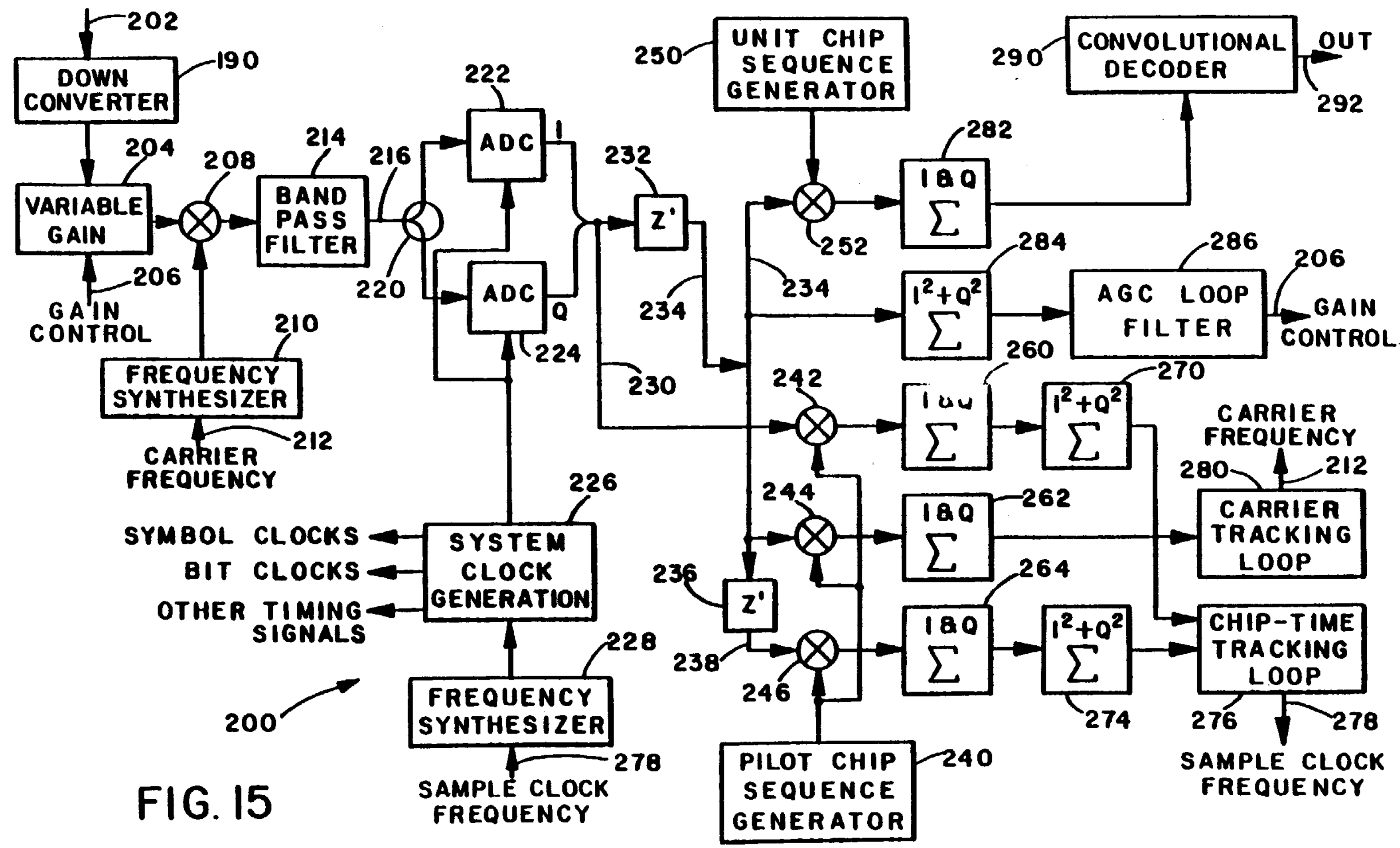
DOWN CONVERTER
VARIABLE GAIN
GAIN CONTROL
BAND PASS FILTER
FREQUENCY SYNTHESIZER
CARRIER FREQUENCY
ADC
I
Q
Z'
SYSTEM CLOCK GENERATION
SYMBOL CLOCKS
BIT CLOCKS
OTHER TIMING SIGNALS
FREQUENCY SYNTHESIZER
SAMPLE CLOCK FREQUENCY
UNIT CHIP SEQUENCE GENERATOR
PILOT CHIP SEQUENCE GENERATOR
I&Q Σ
I^2+Q^2 Σ
CONVOLUTIONAL DECODER
OUT
AGC LOOP FILTER
GAIN CONTROL
CARRIER FREQUENCY
CARRIER TRACKING LOOP
CHIP-TIME TRACKING LOOP
SAMPLE CLOCK FREQUENCY
190 200 202 204 206 208 210 212 214 216 220 222 224 226 228 230 232 234 236 238 240 242 244 246 250 252 260 262 264 270 274 276 278 280 282 284 286 290 292

FIG. 15

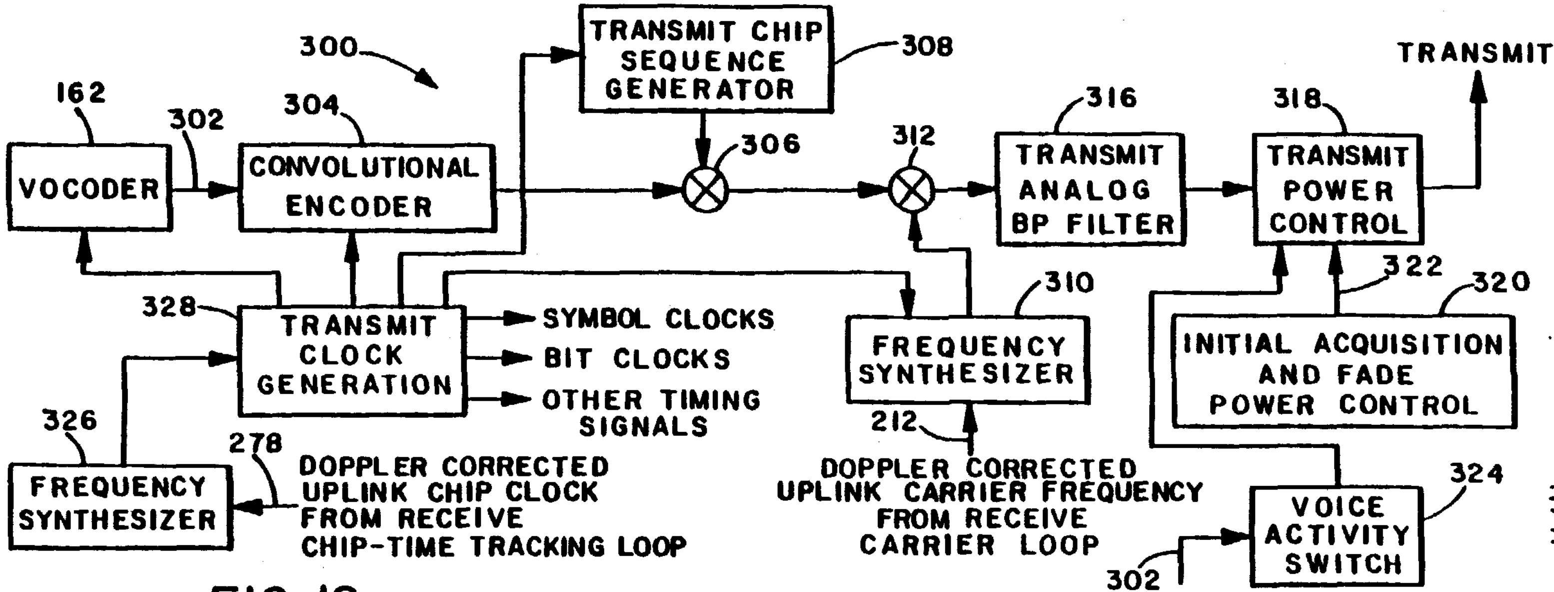

FIG. 16

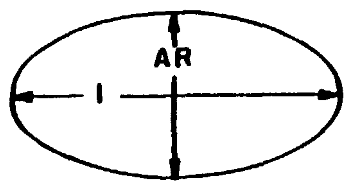

FIG. 12

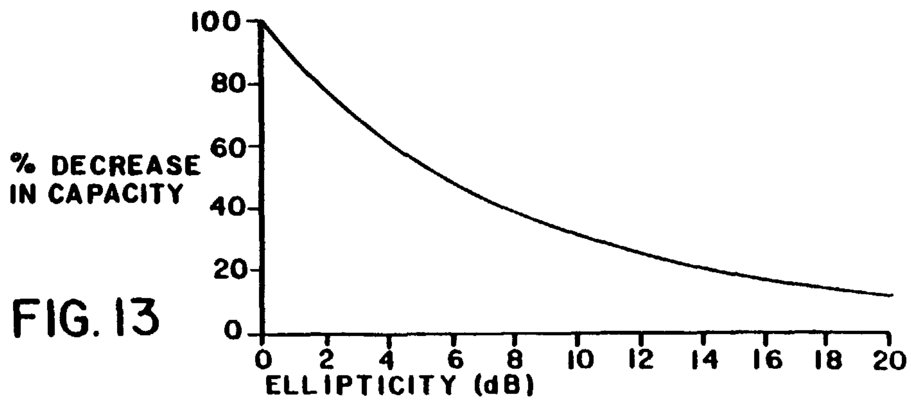

FIG. 13

11/11

SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS

BACKGROUND OF THE INVENTION

Technical Field

The present invention relates to multiple access communication systems and more particularly to a method and apparatus for employing Code Division Multiple Access (CDMA) spread spectrum signals to provide communication services for mobile or remote user terminals using satellite or terrestrially based repeater apparatus. The present invention further relates to utilizing CDMA spread spectrum signals with multiple beam phased array repeater antennas, polarization enhanced omni-directional mobile antennas, voice or data activity switching, adjustable user terminal power control, and L frequency band communication links.

Background

There has been a long-standing need to provide quality communication services to many groups of service users that are classified as remote or mobile or both. These users include rural telephone systems, police and other governmental agencies, commercial dispatching and paging systems, emergency services, and marine telephone. In the past these needs were partially satisfied by land mobile radio. However, these services have always been faced with more potential users than system capacity. The frequency or spectral bandwidth allocations do not provide enough capacity to simultaneously handle the total number of potential users.

Even so, private individuals, businesses, and new classes of users, such as aeronautical communications, are creating an ever increasing demand for services for both mobile and remote users. A large increase in the number of remotely accessible computers and data systems has also created a demand for remote and mobile digital data communications in addition to voice communications. In addition, new types of remote data collection or sensing, and alphanumeric keypad or keyboard entry systems are being proposed which can not be serviced by current communication systems. Therefore, new communication systems are being proposed and built to serve these demands for service.

In building or implementing any new communication system, the key issue for both the designer and the end user is the channel capacity of the system. In a commercial system, capacity translates directly into income or economic feasibility which is important to the system operator, since capacity determines the number of revenue generating users that can be accommodated. The number of allowable users is in turn important to the potential service users. The number of simultaneous users and, therefore, capacity supported by any communication system is determined by the amount of mutual interference between users.

Current mobile radio services operate as frequency division multiplexed (FDM) or frequency division multiple access (FDMA) systems which divide the available bandwidth into smaller bands or channels. To decrease mutual interference some of the bandwidth is also assigned to "guard bands" between channels to provide attenuation or isolation between users. Full duplex communication requires two channels. The total number of channels is generally divided in half, one half being for uplink and call control to a central base repeater and the other for downlink and control signals to users. In addition, some channels may be allocated for additional user protocol and call control. Therefore, the number of simultaneous users is much lower than the apparent number of channels.

System capacity can be increased by increasing the number of channels but this decreases channel bandwidth which limits voice quality and the use of high speed data transfers. Instead, the preferred technique for increasing system capacity is frequency reuse. Frequency reuse is the process of using the same frequency in two separate geographic regions for two distinct communication links as long as the two regions are attenuated or isolated from each other by a minimum value for signal rejection by the two user receivers.

Typical isolation or attenuation requirements for adequate rejection of unwanted signals are on the order of 15 dB (FM type) to 30 dB (AM) or more down from the desired signals. Therefore, a communication system can be subdivided into geographical regions and the same frequency can simultaneously be "reused" in neighboring regions which are isolated from each other by the appropriate attenuation. This technique is easily applied in land mobile radio systems since radio waves are inherently attenuated proportional to the square of the distance from the radiating source (in free space). Systems operating in large urban areas actually appear to experience $1/r^3$ to $1/r^5$ attenuation due to buildings and other absorbing structures.

Users geographically removed from each other by an appreciable distance naturally have their communication signals attenuated with respect to each other. Therefore, a communication system can be constructed using several interconnected base stations positioned so that signals from adjacent stations experience a 15 to 30 dB attenuation with respect to each other. To further increase capacity the geographical regions served by base transceivers are divided into successively smaller sizes which are separated by the appropriate attenuation or isolation, to allow for increased frequency reuse.

This is the basis for cellular telephone technology which is the current approach to accommodating large numbers of mobile users. Here, each cell comprises a geographical region serviced by a central base station which uses land based communication lines and switching systems to form an interlinked system with other base stations so that the only airborne transmissions are localized across the cell. To decrease mutual interference and increase system capacity, frequency use is controlled to assure a minimum amount of isolation between users by assigning channels so that at least one "guard" cell is positioned between two users using the same channel. Each cell is large enough so that signals crossing a cell are attenuated a substantial amount so that they are perceived as lower level noise in distant cells. The cellular system employs a central controller that uses advanced processing technology to keep track of all the channel assignments within the system to maintain the required channel isolation. However, hand-off now becomes a problem. In hand-off, a mobile user crosses from one cell where the current frequency is allowed into a cell where it is not. This requires the system to change the frequencies used for the communication link. If a channel is unavailable in an adjacent cell, the call fails abruptly at cell borders.

A related problem of current channel assignment schemes is the inability to have instant access to the communication system at any time. Channel assignments increase the time the central controller requires to establish a communication link and may even prevent calls from being established.

Cellular systems also suffer from multipath problems, especially near cell borders, where users receive desired signals both from a central transmitter and sources such as reflections from buildings. If the signals add out of phase then they may cancel and become severely degraded. This problem is also encountered in radio telephone and other current mobile systems.

A similar problem occurs for mobile users moving away from central transmitters at speeds that give rise to Doppler effects and phase shifts. Here the standing wave pattern from the transmitter appears to fade every half wavelength creating continual reception problems. In addition, motion on the order of 70 mph can produce Doppler shifts on the order of $+/-80$ Hz at frequencies of 800 MHz which can increase inter-channel interference.

The FM type cellular and radio telephone system broadcasts are not efficient techniques for transferring digital data signals. Current user demands call for data transmission links that are high quality exhibiting very low bit error rates on the order of 10^{-6} or 10^{-8} at data transfer rates on the order of 2400 to 4800 baud with future data transfer rates extending up to 19,200 baud.

Increasing capacity by using smaller cells is useful in large, high user density, metropolitan or urban regions but not in low user density rural regions. Increased capacity is not likely to be achieved economically (cost of base station versus number of users served in region) in rural areas. Therefore, while cellular telephone meets some of the demands of large metropolitan areas it does not meet the demands of rural areas which comprise 25 percent of the population and 84 percent of the land mass for countries like the United States. In addition, larger rural cells can decrease the frequency reuse in adjacent urban areas. This occurs because a single large cell is adjacent to several small cells which cannot use the same frequency. This and other design considerations and problems for cellular systems are discussed in further detail in IEEE COMMUNICATIONS MAGAZINE, Vol. 24, No. 2, February, 1986, especially pages 8-15 which are incorporated herein by reference.

It has previously been assumed that satellite systems are required to economically provide service to low density, rural or remote areas. However, satellite systems generally utilize high volume communication links to transfer otherwise terrestrially based telephone communications over single large distances between terrestrial relay stations for further transfer This does not address the needs of mobile users or system users already without local telephone service.

Some satellite systems have been proposed to address single users through individual antennas instead of central relay stations, but the frequencies at which satellites operate and the methods of transmission have led to the use of rather large fixed antennas which are expensive and not amenable to use in mobile systems.

Proposed satellite services generally operate as FDMA systems employing UHF frequency repeaters and AM modulation schemes such as Amplitude Commanded Single Sideband (ACSSB). Frequency reuse can be used for satellite systems similar to cellular systems discussed above The continental U.S can be divided into geographical regions or cells by using a multiple beam antenna where a separate beam is used for

each region. If the signals in each region or antenna pattern experience an attenuation on the order of say 10 db with respect to those in the nearest neighbor region and 20 dB with respect to the next adjacent regions and so forth, then a given frequency can be reused two regions away based on 20 dB sensitivity rejection. This roughly doubles the number of users allowed at any time within a transcontinental communication system. However, this does not match demand for services.

Antenna designs have been proposed which would scan the antenna patterns across the target geographic regions using advanced frequency scanning techniques. These antenna schemes take advantage of the fact that different frequencies can be reflected at different angles by a given antenna reflector as used on communication satellites. This means that as the frequencies transmitted by the antenna radiator system change, the virtual spot created on the earth by the antenna reflector will move. In this manner the same antenna structure is made to alter the beam location. However, such techniques use the antenna structure to direct different frequencies to different regions, thus failing to fully take advantage of frequency reuse by allocating only a portion of the total spectrum to each region.

Satellite systems do not use terrestrially based repeaters that communicate directly with users or a series of multiple satellites that communicate with the same user. Therefore, current systems do not provide universal service, that is, the ability for users to change position over a large geographical range and still be able to communicate without using alternate transmission equipment or new frequency bands. In multiple satellite systems frequency reuse would be limited by the isolation between geographic target regions. Satellite systems also experience multipath, blocking, and fading problems similar to mobile radio and telephone systems.

Alternate methods of decreasing user interference include time division multiple access (TDMA) or multiplexed (TDM) systems. Such systems use a central receiving station to multiplex or interleave separate user signals in time so that each signal only uses a portion of the total outgoing signal to the satellite. The time division approach divides the total spectrum up into predetermined temporal increments. All signals in the communication repeater system are allocated portions of this time controlled sequence. Therefore, no other user is using the link at the same exact time. The allocated portions are very small and the interleaving very large so that it appears simultaneous to all users. However, this time based synchronization of signals creates a natural limit to the number of users that can be coordinated "simultaneously" which is lower than desired. Also synchronizing a large number of simultaneous users greatly increases the complexity and cost of the system.

What is needed is a communication system that accommodates a larger number of users throughout a variety of user environments from high density urban to very low density rural. The communication system needs to exhibit increased capacity within standard spectral allocation bandwidths but with the same or better communication quality than presently available In addition, a need also exists for a communication system capable of handling high speed low bit error rate digital data transfers at low power densities.

SUMMARY

Therefore, with the above disadvantages present in the art in mind, it is an object of the present invention to provide a multiple access communication system having high simultaneous user capacity.

It is another object of the present invention to provide a communication system having automatic Doppler shift and fade control.

It is a purpose of the present invention to provide a communication system capable of expansion to meet future needs and interface with future alternative communication systems.

It is a further purpose of the present invention to provide an inexpensive communication system user terminal capable of meeting the needs of a variety of mobile or remote users.

It is yet another purpose of the present invention to provide for transmission and receipt of high speed digital data signals with very low bit error rates.

These and other objects, purposes, and advantages are provided in a multiple access, spread spectrum communication system, having means for communicating information signals to, from, or between a plurality of users, using code-division-spread-spectrum communication signals and isolation means for providing marginal isolation between said user communication signals. The isolation means can comprise a phased array antenna coupled to means for generating substantially simultaneous multiple steerable beams; an antenna structure configured to obtain either one or both of two circular polarization states; transceiver means for transmitting or receiving the same communication signals by two or more locations to create constructive interference maximized signal reception; first power control means for adjusting an output power duty cycle for said code-division-spread-spectrum communication signals in response to a predetermined activity level for said information signals; or second power control means for adjusting said output power level for said code-division-spread-spectrum communication signals in response to a minimum power level required to complete a communication link.

The preferred embodiment of the multiple access, spread spectrum communication system of the present invention further comprises means for transmitting a predetermined pilot chip sequence to users contiguous with said code-division-spread-spectrum communication signals.

In a preferred embodiment the means for communicating comprises chip generation means for generating a plurality of quasi-orthogonal spreading functions; code selection means for assigning one of the spreading functions to a user; and a plurality of mobile user terminals capable of transmitting or receiving code-division-spread-spectrum communication signals. Each of the user terminals uses a transmitter for generating a code-division-spread-spectrum communication signal according to an assigned spreading function in response to an input information signal; a receiver for detecting a code-division-spread-spectrum communication signal and generating an output information signal according to said assigned spreading function; and an omni-directional antenna. At least one repeater is used for receiving communication signals from the plurality of user terminals and for translating the code-division-spread-spectrum communication signals to a form suitable for transfer to an intended recipient.

In a further aspect of the invention the repeater preferably employs means for transmitting a predetermined pilot chip sequence to users contiguous with a communication link and the receivers include a pilot sequence tracking loop. An activity detector is included in the repeater for sensing signal activity levels in said information signals and decreasing repeater transmission power duty cycle in response to a decrease in sensed activity below a predetermined threshold level for a predetermined sampling time.

The user terminals can also comprise an activity detection means for sensing signal activity levels in the input information signals and decreasing user terminal transmission power duty cycle in response to a decrease in sensed activity below a predetermined threshold level.

The terminals can further comprise power control means for sensing a received power level present in received code-division-spread-spectrum communication signals and for adjusting the output level power applied to an antenna for transmitting code-division-spread-spectrum communication signals in response to the sensed power level.

The antenna of the preferred embodiment further comprises polarization control means for adjusting the antenna so as to select a predetermined polarization mode.

In further aspects of the invention the repeater means can comprise at least one terrestrially based repeater or at least one satellite based repeater or both. The communication system preferably employs at least two satellites and earth based repeaters. Generally the satellite repeaters are interconnected to other communication systems using a central control station known as a hub. Users can access either type of repeater based on their location and assigned communication links. In this manner universal service is obtained in a manner previously unavailable and terrestrial repeaters in high user density regions can offload local users to decrease the power drain on satellites or increase their capacity. The repeaters preferably use a phased array antenna structure to create simultaneous multiple steerable beams.

In still further aspects of the invention the communication system further comprises a demodulator, using a radio frequency mixer to correlate a local reference signal with input code-division-spread-spectrum communication signals. The resulting intermediate frequency spread spectrum signal is filtered to remove undesirable frequency components. A phase division means connected in series with the filter divides the spread spectrum signal into an analog in-phase signal and an analog quadrature signal which are then converted into digital in-phase and quadrature signals at a variable rate. Combiner means transfers the digital in-phase and quadrature signals onto a single data line in serial fashion for processing by other components within the demodulator.

A pilot chip reference means generates a local bit sequence corresponding to a predetermined pilot chip sequence transmitted contiguous with communication signals received by the demodulator. Carrier tracking means connected to the combiner and the pilot reference means compares the local pilot chip sequence to received signals in a timed relationship to determine the timing of the code-division-spread-spectrum communication signals with respect to the said local pilot chip sequence. A decision is then made to adjust the frequency of the local mixer frequency source. Chip synchronization means connected to the combiner and the pilot reference means compares the local pilot chip sequence to received signals in a plurality of timed relationships to determine the timing of code-division-spread-spectrum communication signals with respect to the local pilot chip sequence. The comparison determines if the rate for the analog-to-digital conversion needs adjusting.

Unit chip means generates a bit sequence corresponding to an assigned spreading function which is used by despreading means connected to the combiner for generating despread-spectrum in-phase and quadrature information signals. These signals are then combined in an output means to form an output information signal.

The present invention provides a method of providing high capacity multiple access communications to a plurality of communication service users, by converting a plurality of narrow band analog input or digital data input signals into a plurality of wide band code-division-spread-spectrum communication signals, using an assigned spreading function and a predetermined carrier frequency; applying marginal isolation to the plurality of code-division-spread-spectrum communication signals; transmitting the code-division-spread spectrum communication signals to or from users; and converting a code-division-spread-spectrum communication signal received by a user to a narrow band analog or digital information signal.

The method of the present invention may also comprise the steps of transmitting a pilot chip sequence and transmitting and receiving signals through repeaters. The repeaters can include at least one terrestrial and/or at least one satellite based repeater.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of the present invention may be better understood from the accompanying description when taken in conjunction with the accompanying drawings in which like characters refer to like parts and in which:

FIG. 1*a* is a plot of antenna gain versus angular deviation from boresight center for an exemplary antenna used in a satellite communication system;

FIG. 1*b* is a table of actual and "weighted" users versus antenna gain and angular deviation for the antenna of FIG. 1*a* when used in the communication system of the present invention;

FIG. 2 is an overview of a communication system constructed according to the principles of the present invention;

FIG. 3, is a schematic of a repeater employed in the system of FIG. 1 using an omni-directional antenna;

FIG. 4 is a graphic plot of average user power to establish a communication link versus the distance from a terrestrial repeater;

FIG. 5 is a schematic of another repeater employed in the system of FIG. 2 using a phased array antenna structure;

FIG. 6 is a graphic plot of average user power versus the distance from a repeater;

FIG. 7 is a schematic of an orbital repeater and a communication system hub used in the system of FIG. 2;

FIG. 8 is a plot of relative signal strength versus position for a satellite interference pattern;

FIG. 9 is a schematic view of a hub interferometer communication link;

FIG. 10 is a schematic of the user terminal employed in the system of FIG. 2;

FIG. 11 is a view of an antenna for use in the system of FIG. 2;

FIG. 12 is an illustration of elliptical ratio;

FIG. 13 is a graphic presentation of capacity versus antenna ellipticity;

FIG. 14 is a tabular listing of capacity versus ellipticity and axial ratio;

FIG. 15 is a schematic of a demodulator used in the user terminal of FIG. 10; and

FIG. 16 is a schematic of a modulator used in the user terminal of the FIG. 10.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention comprises a new communication system employing one or more satellite or terrestrially based repeater stations to provide communication links among a large number of mobile or fixed, and local or remote users. To obtain a large number of users, the user terminals within the communication system employ new modulators and demodulators to transmit forward-error-correcting-coded communication signals using Code Division Multiple Access (CDMA) spread spectrum transmission signals. In addition, system capacity and communication is further enhanced by using means for providing marginal isolation between users comprising multiple beam phased array repeater antennas, polarization enhanced mobile antennas, means for generating interference patterns for reception and transmission of communication signals, voice or data activity switching, or adjustable user terminal power control. Additionally, independent pilot chip sequence signals are used to improve acquisition and tracking.

Traditionally, CDMA has been held to be inferior as a multiple access technique in comparison to FDMA and TDMA because it appeared to provide inferior spectral utilization. This was based on the argument that for TDMA or FDMA, the number of equal bandwidth channels that a given band can be divided into is approximately equal to the total bandwidth divided by the bandwidth per user channel. Whereas, CDMA provides fewer channels according to the following argument.

In a bandwidth limited environment where a number of equal users desire to share a common frequency band using CDMA, the number of such equal users is determined by the following formula:

$$I/S = W/R - E_b/N_o \tag{1}$$

where

- I is the total interference power seen by each user's receiver and is equal to the total power of all the users, which is equal to the number of users times the power per user;
- S is the power of one user's signal, thus I/S equals the effective number of users;
- W is the bandwidth occupied by the spread spectrum signals;
- R is the data rate of each user; and
- E_b/N_o is the signal-to-noise ratio required for the modulation and coding system employed

Since it can be seen that W/R is the TDMA and FDMA capacity, the CDMA capacity would seem to be always less by an amount equal to E_b/N_o, for practical systems, approximately 3-5 dB, depending on the particulars of the modulation and coding system employed.

The present invention greatly increases the capacity of CDMA systems by employing means for producing marginal isolation. The term, marginal isolation, will be defined herein. The key idea is that the spread spectrum receiver sees the weighted sum of all the users' incident power as interference to the one desired signal. If the system includes means to provide non-uniform weighting, then increases in capacity can be obtained from differences in weighting. Differences too small to be of use to FDMA or TDMA systems are quite valuable to a CDMA system.

In previously proposed CDMA satellite systems, a wide band transponder with earth coverage antenna has been employed. Such an antenna provides nearly the same gain to all users, so marginal isolation is realized and performance is, in fact, worse for CDMA than for TDMA or FDMA. The present invention, however, utilizes a multiple steerable beam antenna which provides the capability to realize marginal isolation. Such an antenna also increases the capacity of FDMA and TDMA systems, but provides far more capacity gain for CDMA. This is because FDMA and TDMA systems require at least 15 dB isolation of co-channel signals in order to provide acceptable performance, while the CDMA system obtains useful capacity increases from isolation as small as 1 dB.

Marginal isolation is defined as a system characteristic that provides unequal weighting of the incident received power of interfering user signals. Embodiments of the present invention utilize several mechanisms for providing marginal isolation, including multiple steerable beam antennas, antenna polarization, formation of interference beam patterns from multiple satellites, path loss differentials for interferors at different distances, and less than continuous transmit duty cycle. Additional methods of producing marginal isolation may be devised by those skilled in the art of communications system design.

An exemplary communication system 30 would use a spread spectrum bandwidth, W, of 8 MHz and an information signal bandwidth, R, of 5 kHz for a bandwidth ratio of 1600 and a processing gain of 32 dB. If we assume E_b/N_O to be 5 dB, the number of users can be computed from equation 1. Under these conditions I/S is 27 dB. The total number of users (I+S) is, therefore, approximately 500. This means that the communication system supports 500 users under these conditions. But these are users all operating under the same conditions and with equal power and isolation within the system.

If instead the system users are isolated or contribute unequally to the interference in the system communication link, new users can be added. This can be illustrated using an antenna pattern that exhibits a relatively flat "response" or gain across the middle of a beam width and then falls off sharply on the edges. If we assume an equal distribution of users over an area larger than the central high gain portion of the antenna beamwidth, then each user is "weighted" by the relative gain effected for its signal because of a roll-off in gain. FIG. 1, shows the impact of this roll-off for a communication system.

FIG. 1*a* shows a plot of the actual, maximum, and minimum gains versus single-sided angle from boresight of a typical satellite antenna used for L-Band transmission from synchronous orbit. This antenna pattern represents an antenna optimized for an FDMA system, not a CDMA system. FIG. 1*b* shows the minimum and maximum gain data in a tabular form with gain regions and angles expressed as double-sided or total angle from the center of the boresight. If we use the maximum gain in each region and the gain factor for the entire region and assume that there is a uniform distribution of users across the typical 7.4° width of the United States, then FIG. 1*b* shows how a total population of 2326 users has the same effective interference as 500 users having the strength of the user of interest.

The "Δ Angle" column gives the angle size of each gain range. The "# of Users" column is calculated by multiplying the total number of users by the fraction of users at this gain. The following equation is used:

$$\#\text{ of Users} = \frac{\Delta\text{ Angle}}{\text{Total Angle of } US}\ \text{Total Users} \qquad (2)$$

The "Weighted # of Users" column is calculated by multiplying the "# of Users" column by the maximum gain of that range. This calcuates the equivalent number of users at 0 dB that would produce the same interference as the users in this region at this maximum gain. The following equation is used:

$$\text{Weighted \# of Users} = \#\text{ of Users}\ 10^{-(\text{MaxGain}/10)} \qquad (3)$$

It is important to note how even attenuations of as small as 1 dB reduce the weighted total. Lastly, the "Weighted # of Users" is totaled. The number of users in the U.S. was adjusted for purposes of illustration so that the "Weighted Total" was approximately 500 users as used above.

The "CDMA Reuse Factor" of 4.65 was calculated as the ratio of 2326:500. The "FDMA Reuse Factor" of 3.70 was calculated as 7.4°/(1.0° 2). 7.4° is the width of the U.S., 1.0° is the 2 dB beamwidth of the antenna, and one needs to use one half of the frequencies in one beam and then the other half in the next beam; so it takes two beamwidths before the frequencies. Using the antenna optimized for FDMA, CDMA shows a better reuse factor. If the same size antenna is optimized for CDMA—minimum noise beamwidth—then the CDMA reuse factor can be further increased to 6.67 giving a reuse gain of 6.67/3.70=1.80.

As can be seen, the total number of "effective" users is 500 while the system is actually supporting 2326 users if multiple beam positions are provided so that all users can be received near the center of a beam. Therefore, the system uses marginal isolation of a few dB, which is useless to other systems, to provide frequency reuse. This ability to increase the effective adjacent user attenuation allows the present communication system to provide greatly increased frequency reuse as compared to other communication systems.

An overall schematic of a communication system operating according to the principles of the present invention is illustrated in FIG. 2 In FIG. 2, a spread spectrum communication system 10 employs terrestrial repeaters 12 or orbital repeaters 14 with one or more central stations 16, to transmit and receive information to or from mobile terminals 20, or 22, and fixed terminals 24 or 26.

The term information is used to encompass both digital data and voice since some terminals will transmit, or be equipped to transmit, signals in the form of digital data as well as the typical analog or voice signals Transmission of digital data is generally accomplished using an appropriate interface for linking a data generation source 28, such as a TTY device or computer, with the user terminal 22 or 26 circuitry. Modems and other data communication interface devices are readily designed